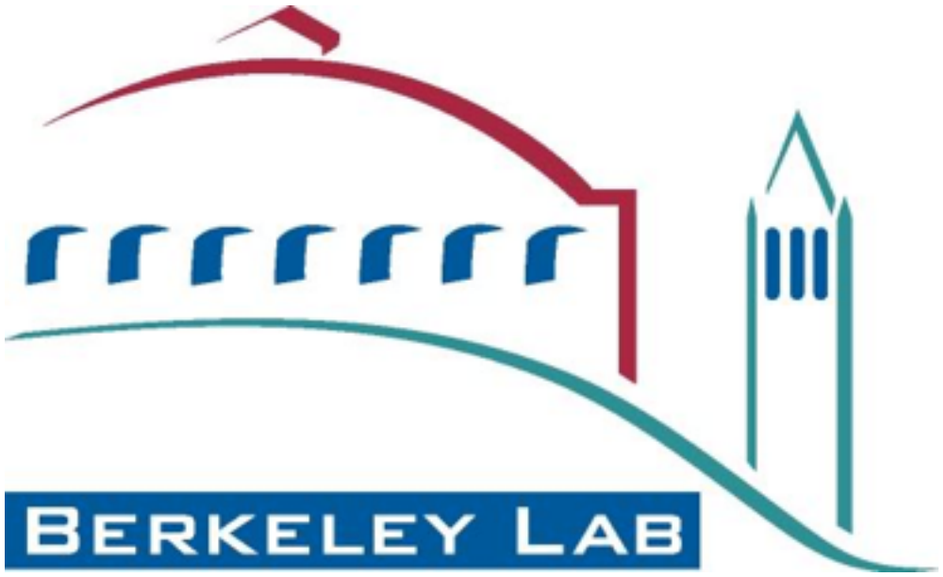
Near-Term Measurements: Neutrons



Victor M. Gehman

Workshop on LBNE Physics

Santa Fe, NM

April 26, 2014

Outline

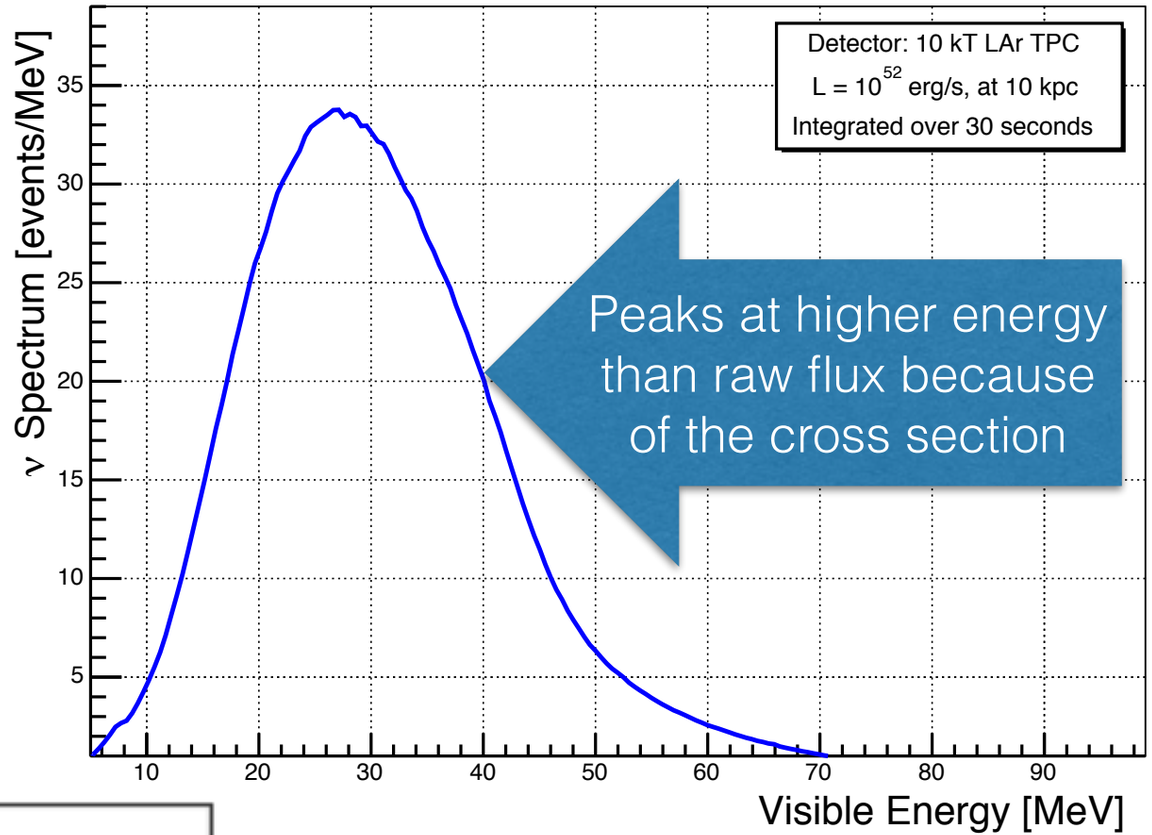
- **CAPTAIN WNR Runs:** reconstructing neutrons for fun and profit at energy ranges that are important for LBNE
- **Supernova neutrinos:** the signal
- **Cosmogenic argon activation:** BACON and CAPTAIN
- **A few words about neutrino oscillations:** neutrons are sneaky
- **A beautiful mess:** lots of things can happen in argon
- **Conclusions:** this is not just an R&D project, we've got a lot of physics to do here!

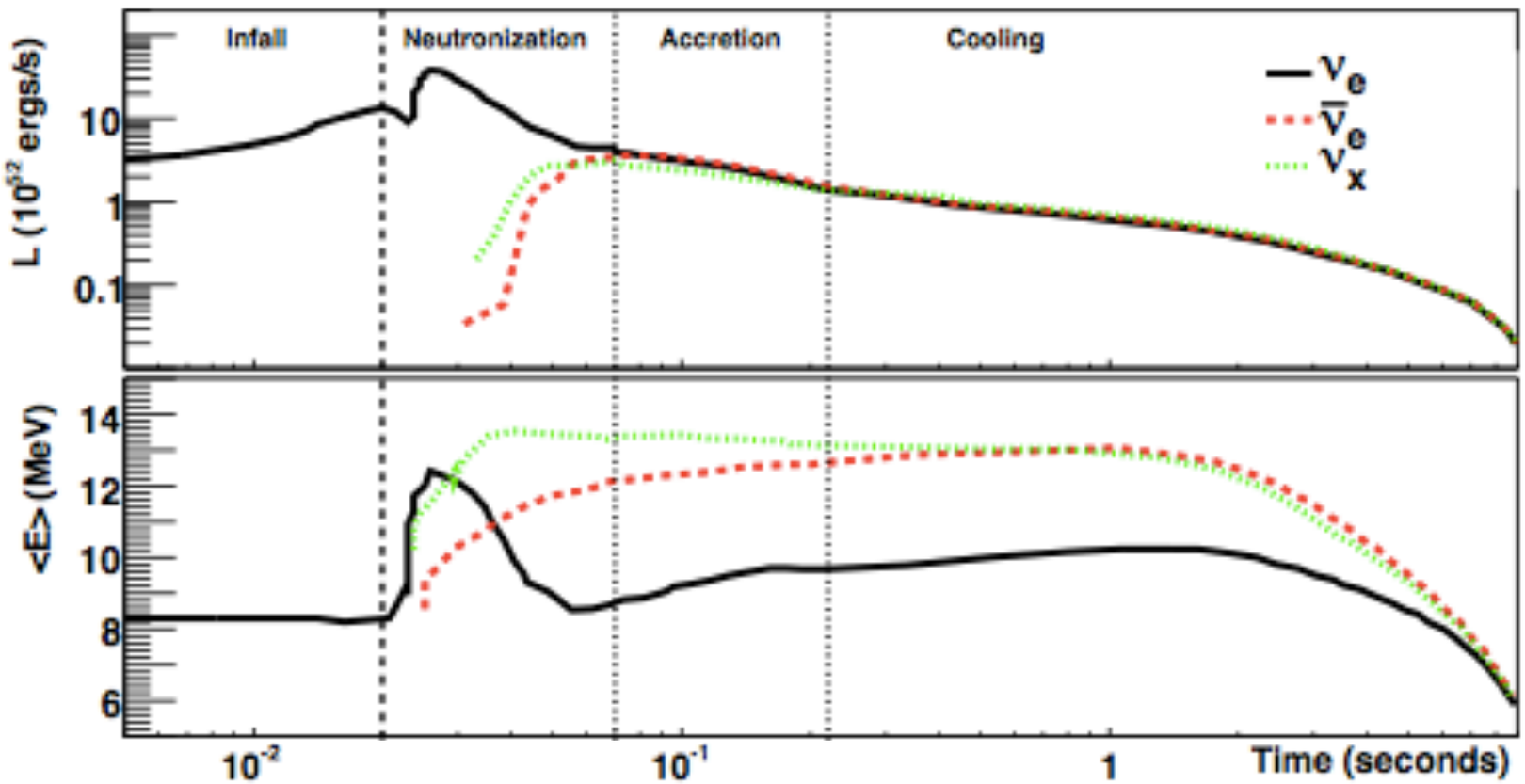
CAPTAIN WNR Runs

- High intensity run: look for neutron activation of the argon
- Low-intensity run:
  - (Low energy) look at neutrino-like interactions, esp. final state de-excitation gammas
  - (High energy) build a library of neutron event topologies, to help with neutrino energy reconstruction, especially with respect to pion production in liquid argon

Supernova Signal

- Supernova signal is at much lower energy than the LBNE oscillation analysis
- But there is a lot to be learned from both the spectrum and its time evolution





Changes the amplitude of the above spectrum as a function of time

Changes the location of the peak in the above spectrum over time

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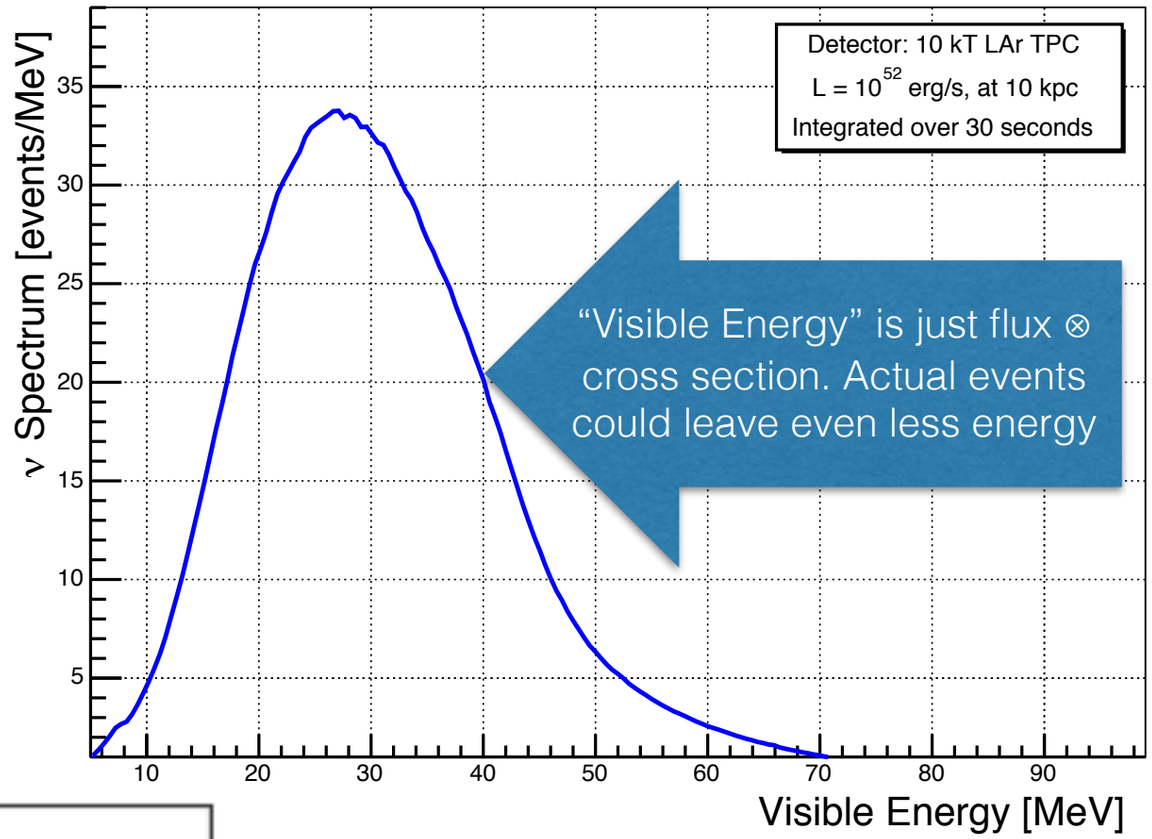

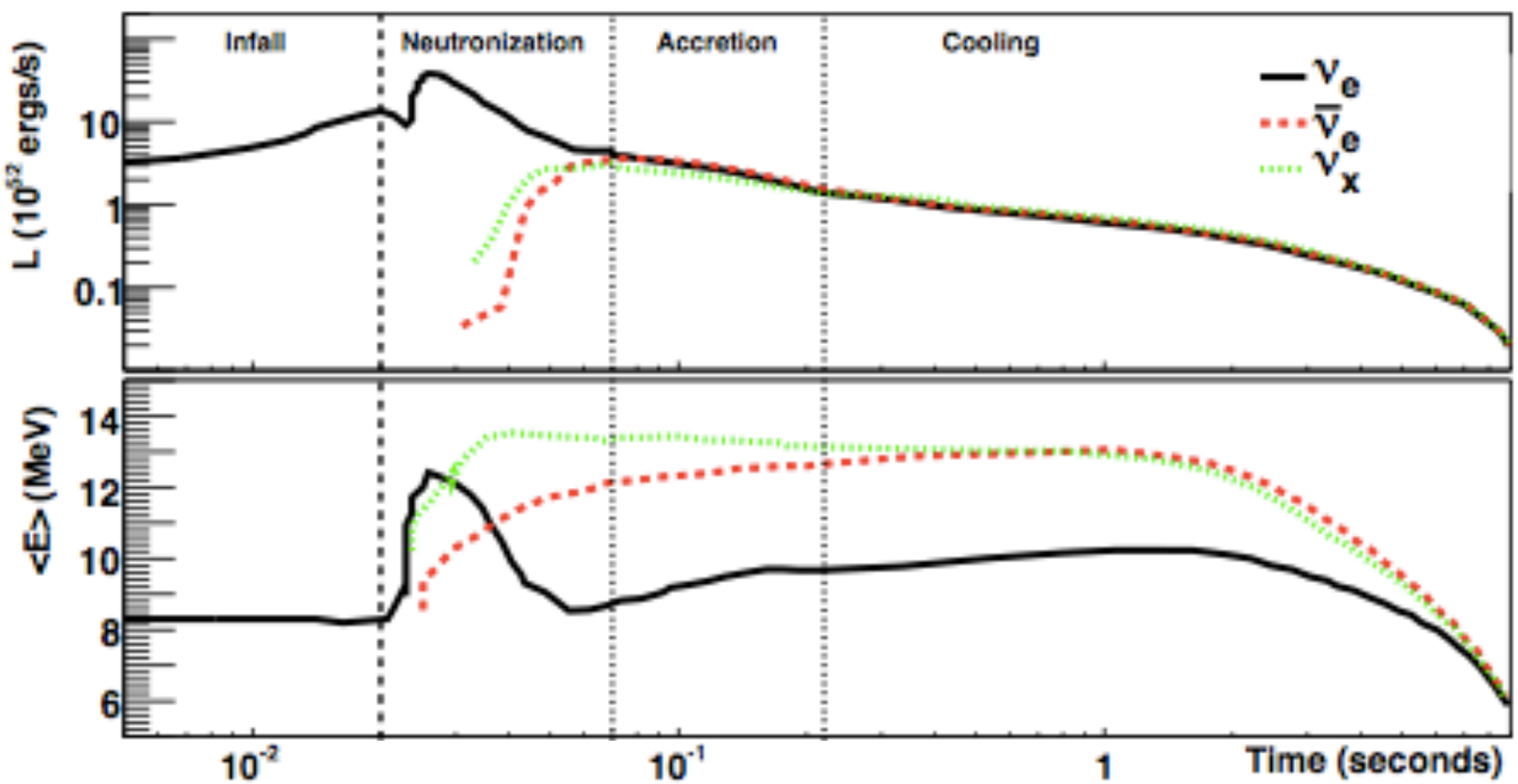

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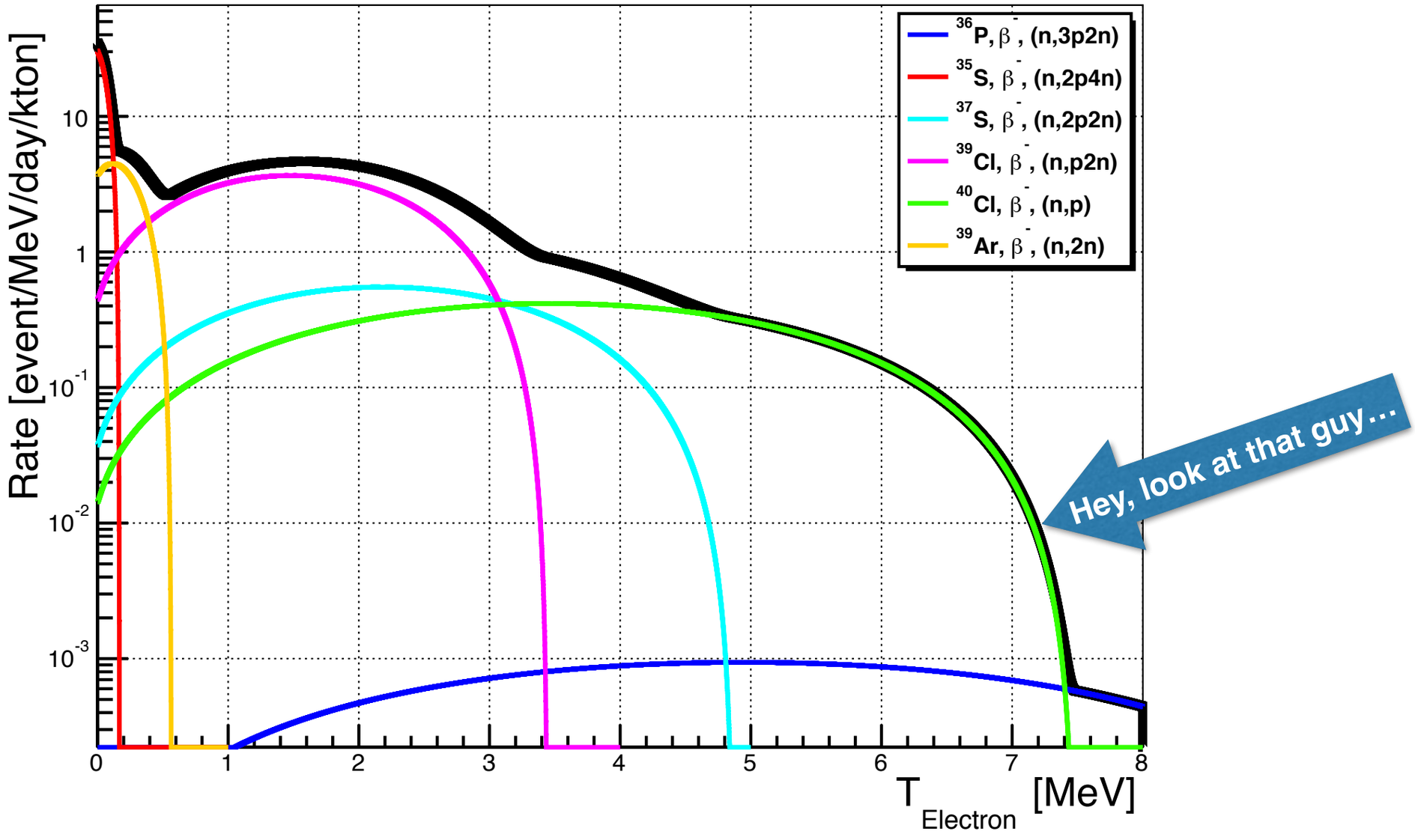
Changes the location of the peak in the above spectrum over time

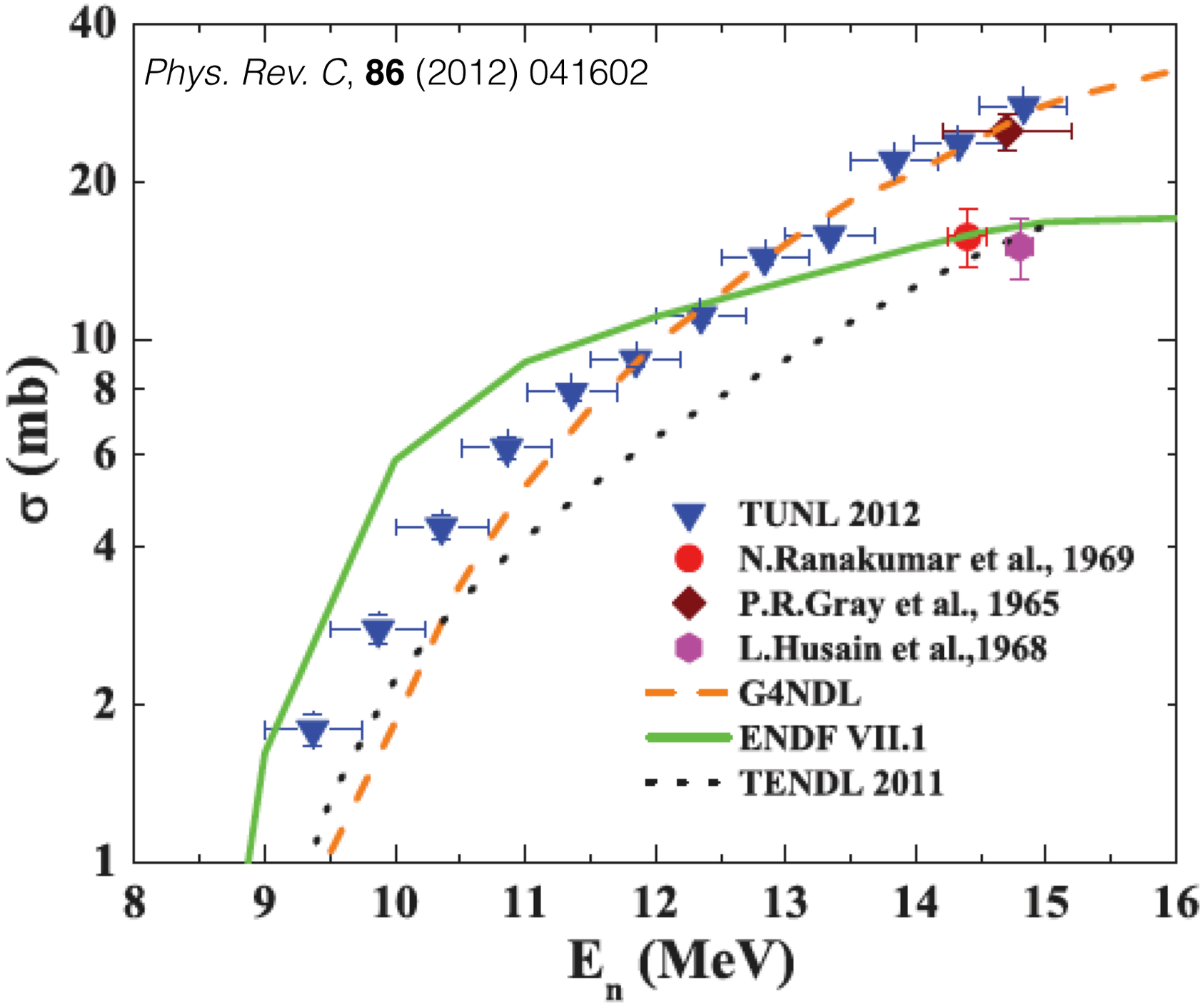
Different Energy, Different Backgrounds

- To see the supernova signal, we would like a threshold below 10 MeV, but…
- This gets us to a range where we have to start worrying about radioactive decays from cosmogenic isotopes,



Wait… ^{40}Cl?

- This stuff is just made with ^{40}Ar(n,p)^{40}Cl. Hasn't this been measured and calculated before?
- Well, sort of…
- No data above 15 MeV, and the calculations disagree by a factor of two
- It would be really nice to even see the peak of the production cross section…



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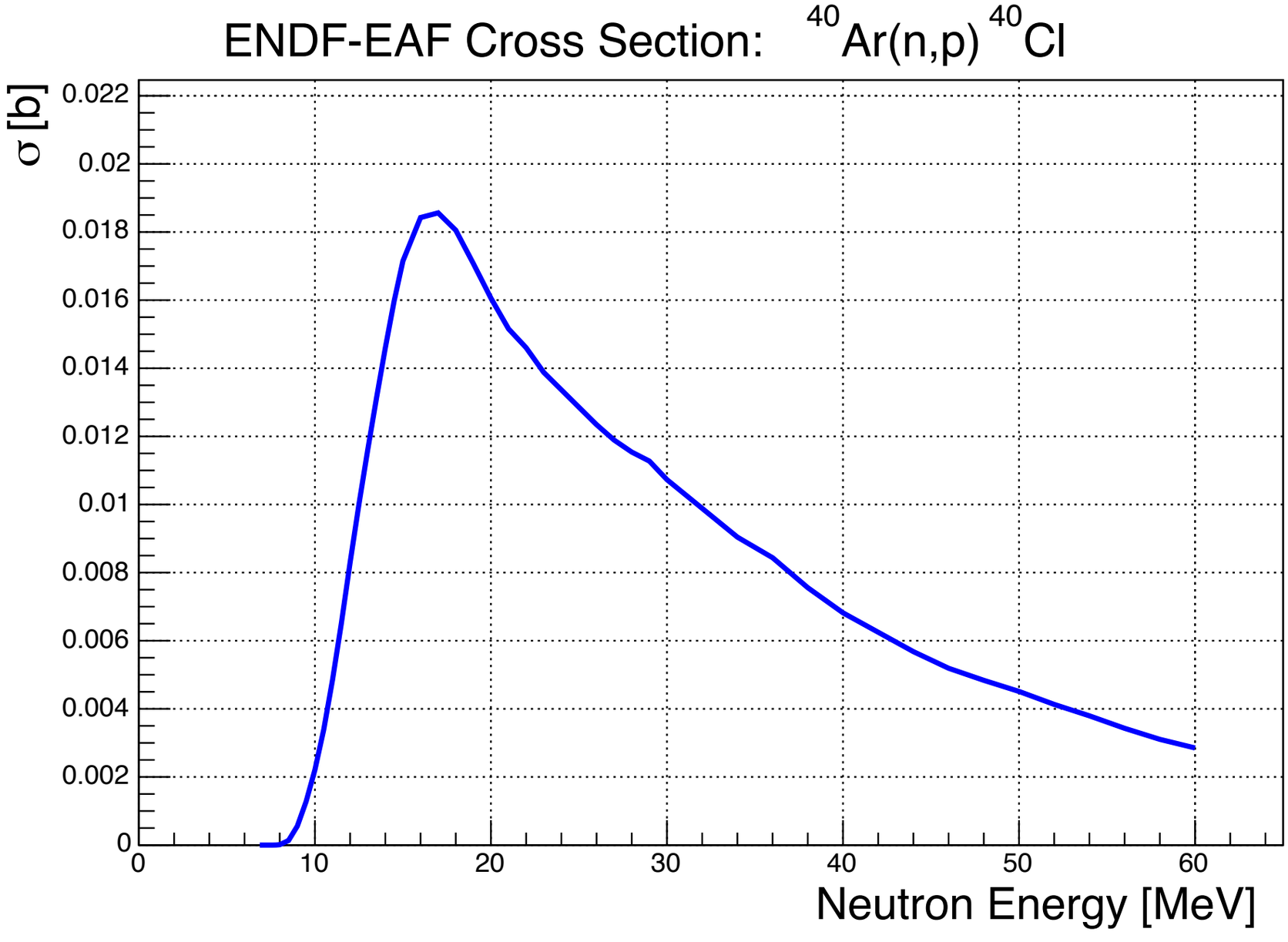
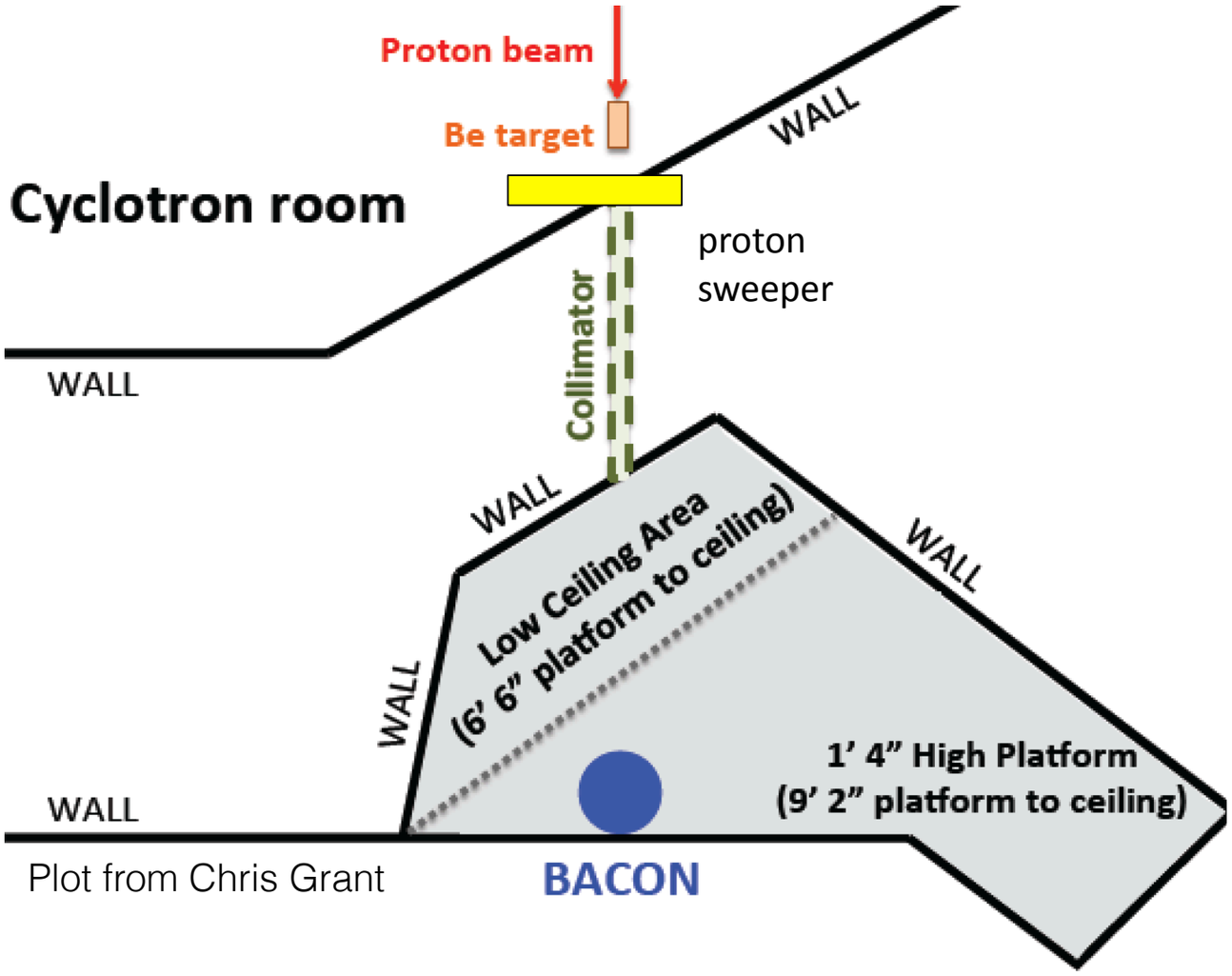
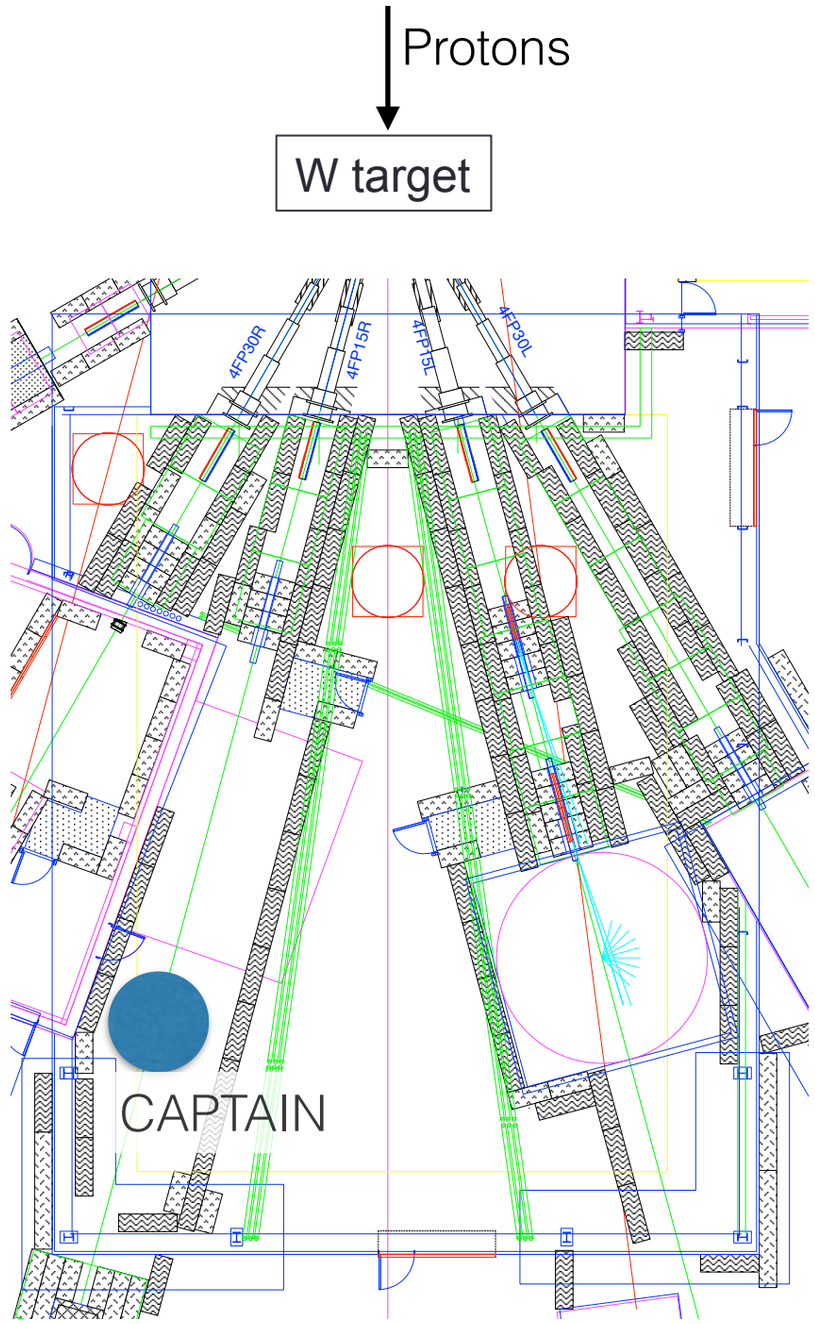


Two Sets of Measurements





At UC Davis with BACON

At LANL with CAPTAIN

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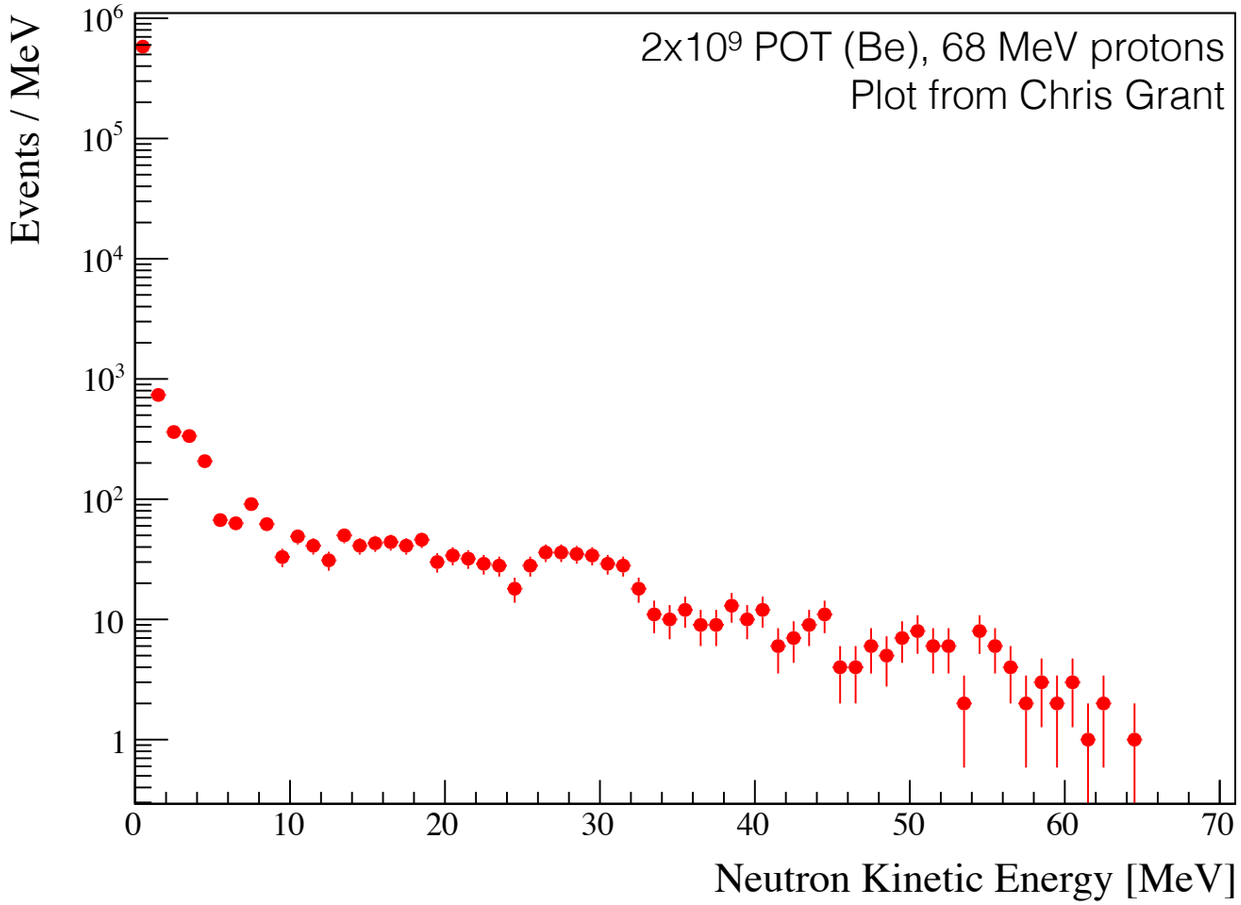

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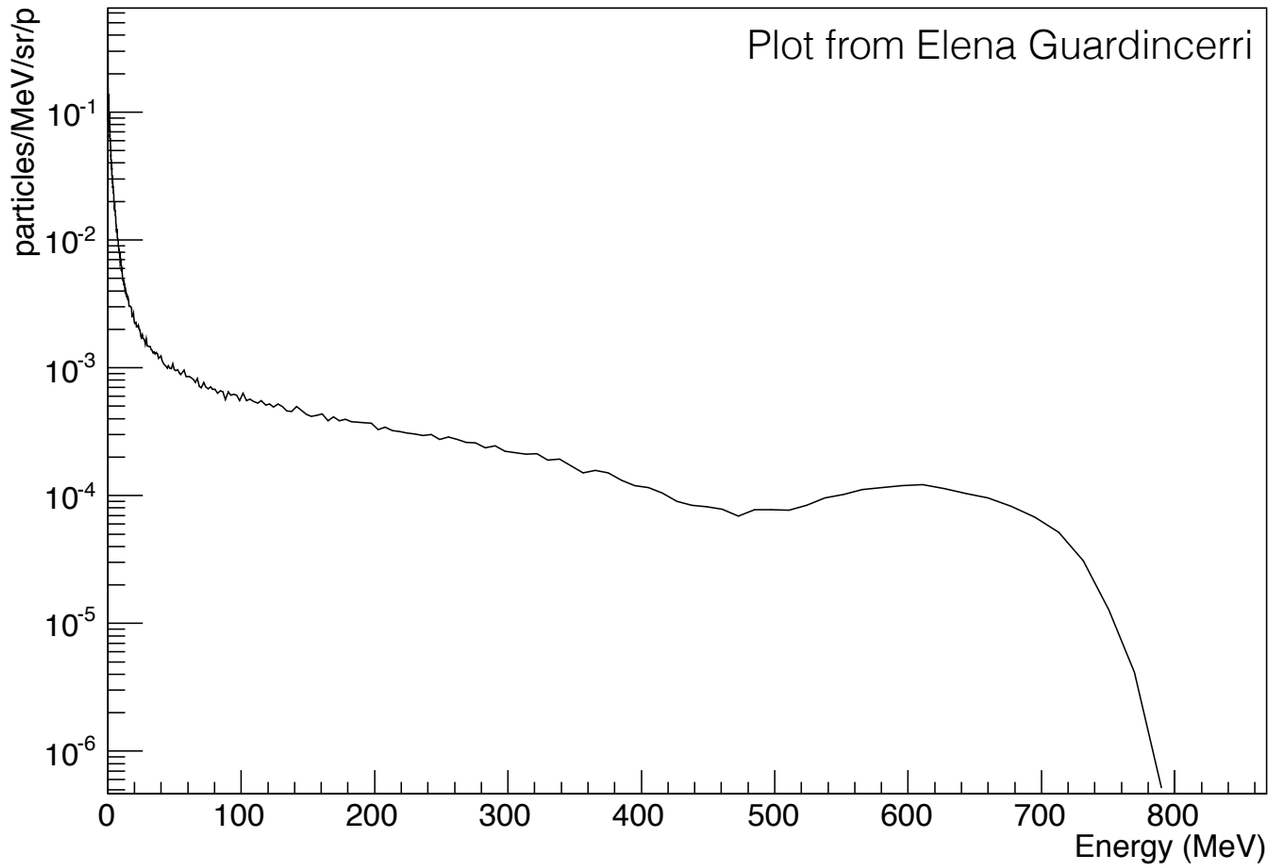

At LANL with CAPTAIN

BACON at UC Davis

- BACON (Big Argon Counter of Neutrons) is a scintillation only LAr detector with a well geometry (built with NA22 money at LANL).

- Ran at LANSCE in Nov. 2013, being shipped to UCD immanently for neutron running there.

- Will cook BACON with neutrons until ^{40}Cl hits saturation, then watch it decay away with its 90-second half life, and extract the production cross section.

- Also planning a side measurement at UCD with small LAr dewar and a HPGe counter

BACON at LANL/LANSCE/WNR in November 2013

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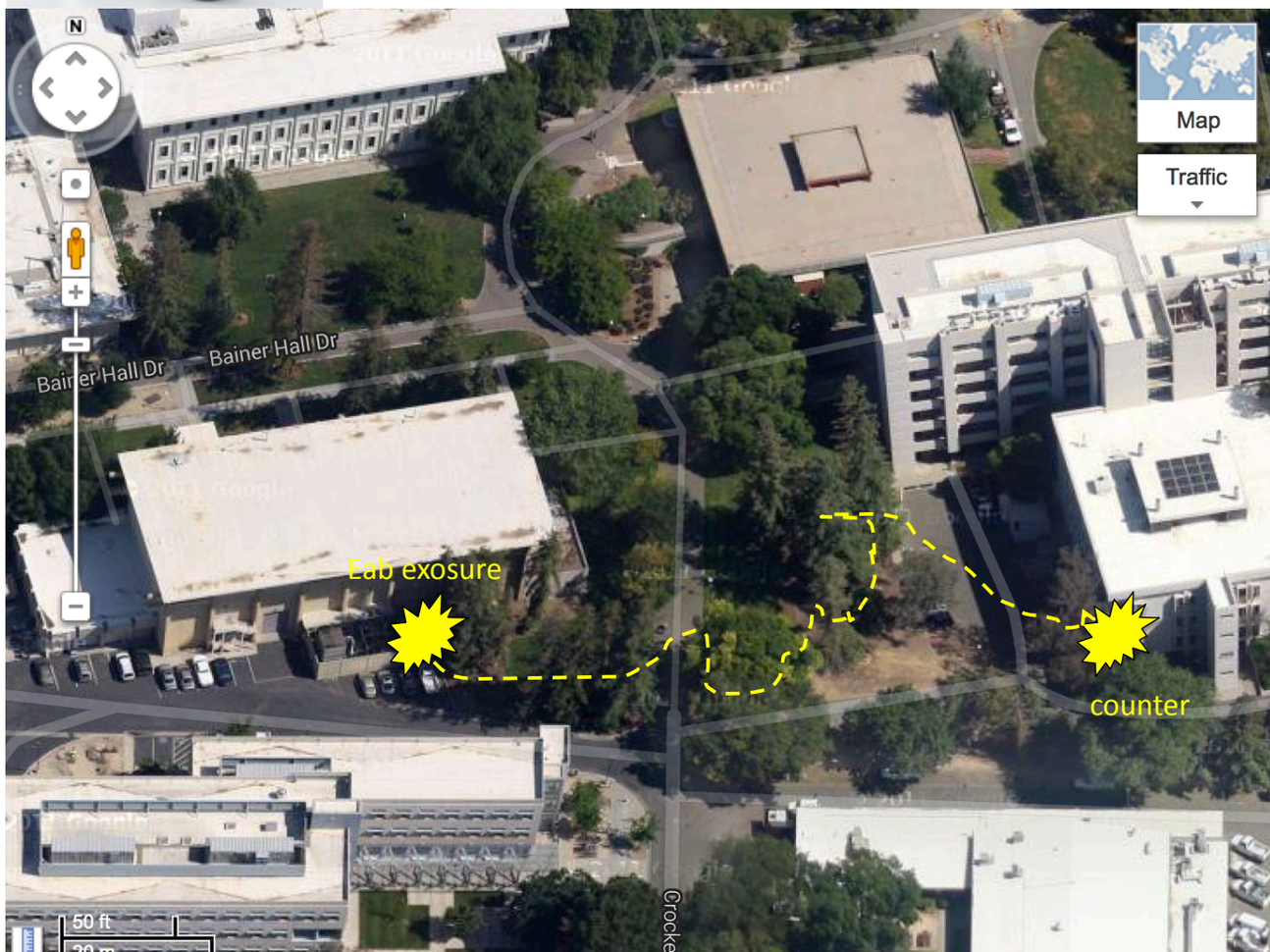
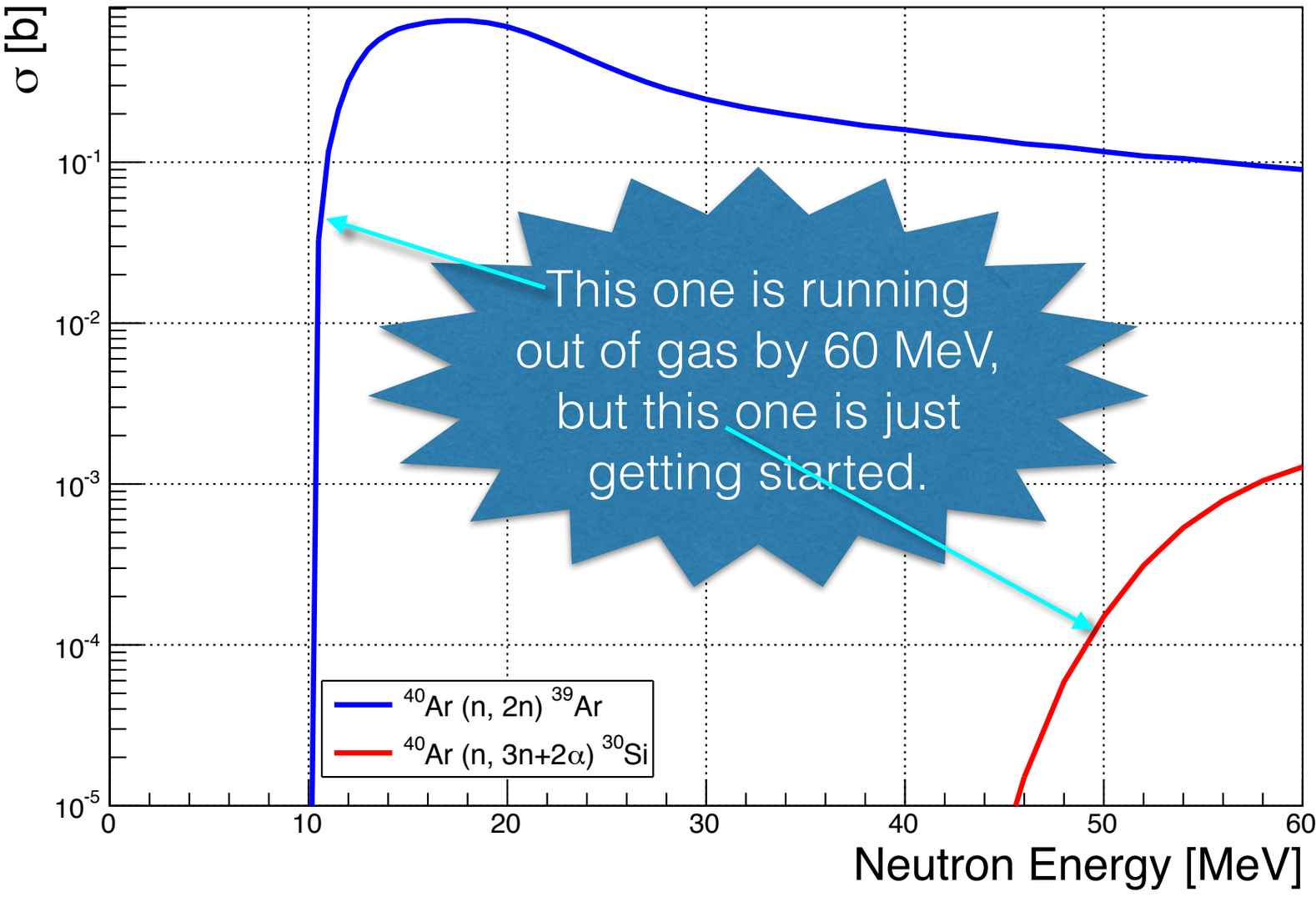
neutron beam



(n,X) Cross Sections at LANSCE

- The beam at UCD, and ENDF only go up to about 60 MeV.
- Some cross sections turned off by then, some have not!
- The LANSCE beam has a much higher energy, and CAPTAIN has much more information for each event.
- This will let us look for many more neutron activation products.
- The BACON program is a great start, but is not enough!



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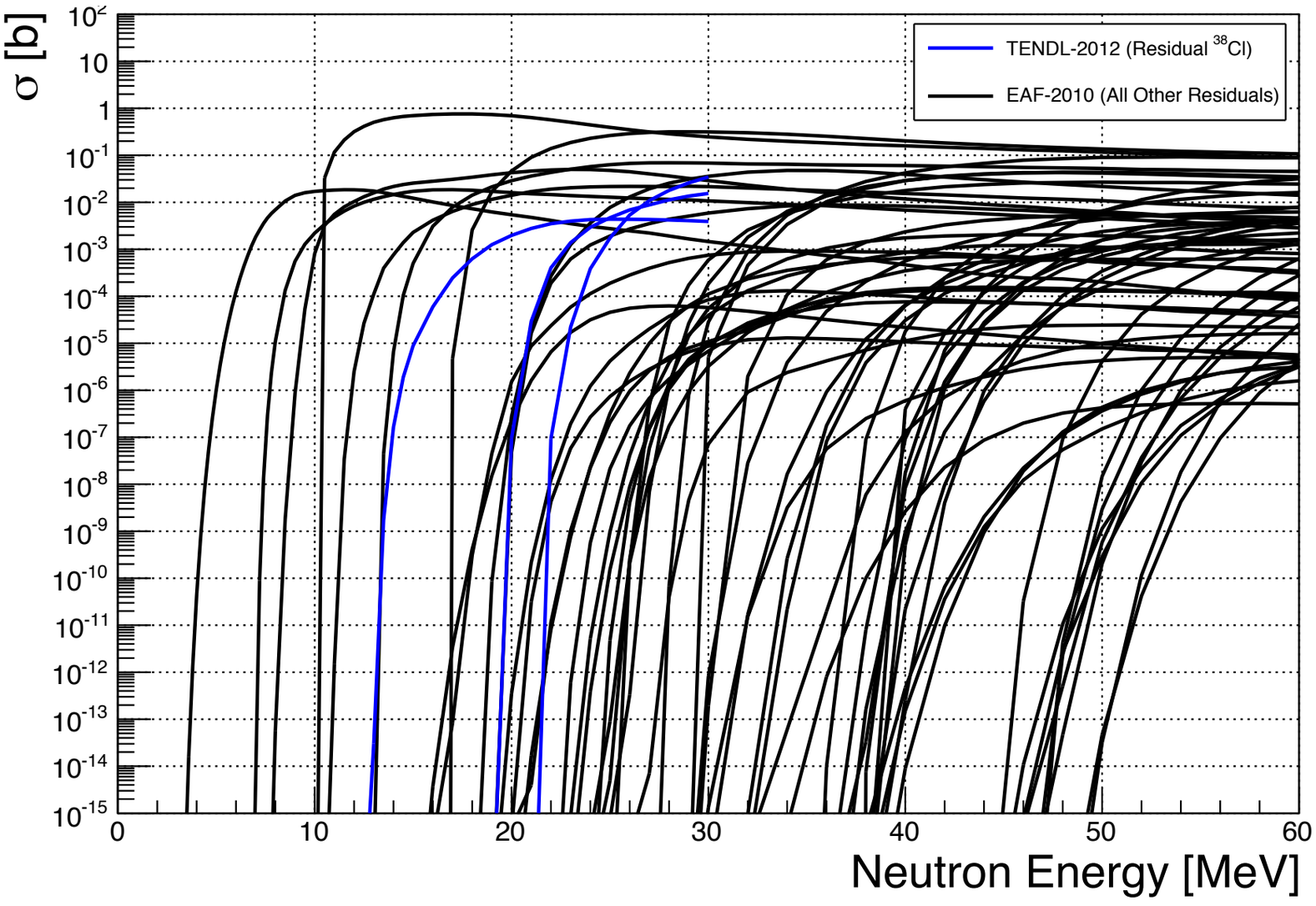
There are a lot of cross sections to worry about, and these are just the ones in ENDF!



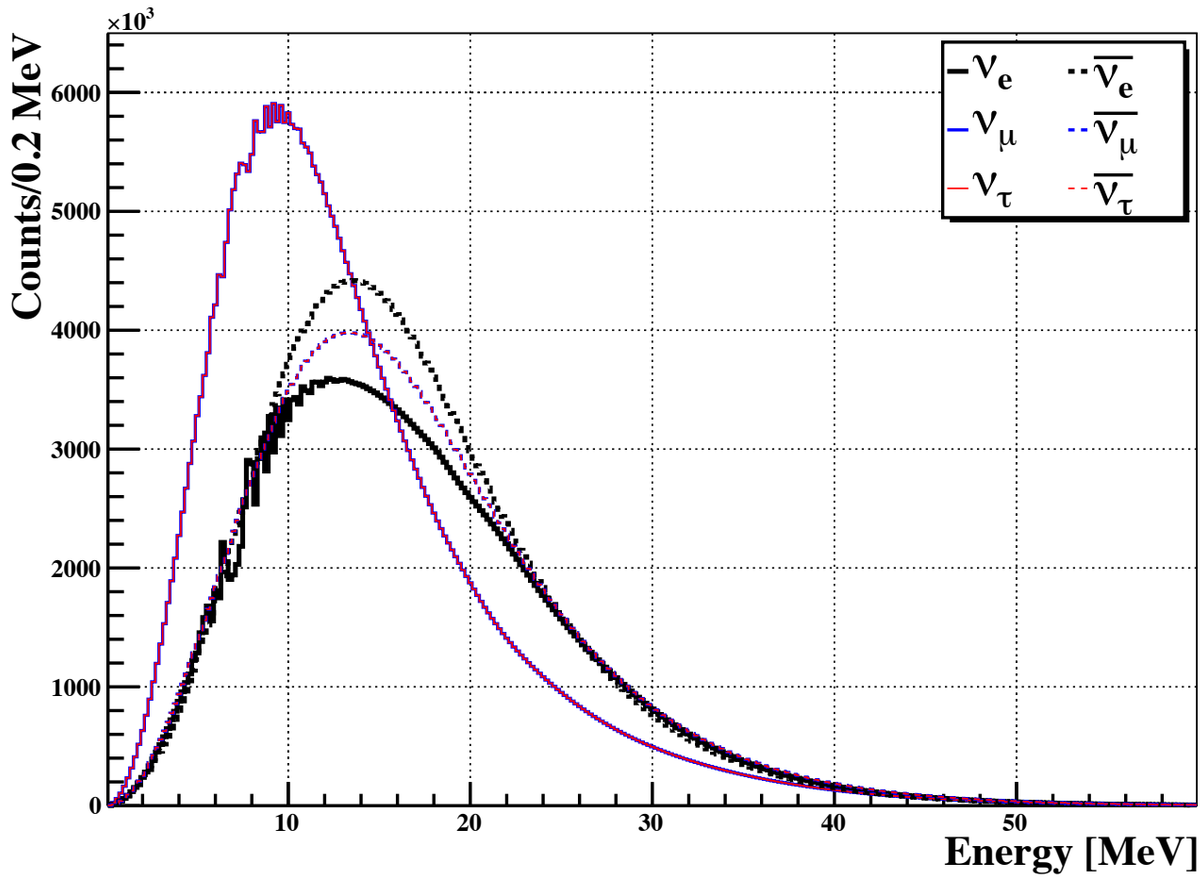
Argon De-Excitation Gammas

- Most of the counts in the observable spectrum come from the charged current interaction:

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

- There is also a neutral current interaction that could help normalize the total neutrino flux:

$$\nu_x + {}^{40}\mathrm{Ar} \rightarrow \nu_x + {}^{40}\mathrm{Ar}^*$$



- The low-energy, low-intensity neutron run in CAPTAIN will allow us to look for the de-excitation gammas through:

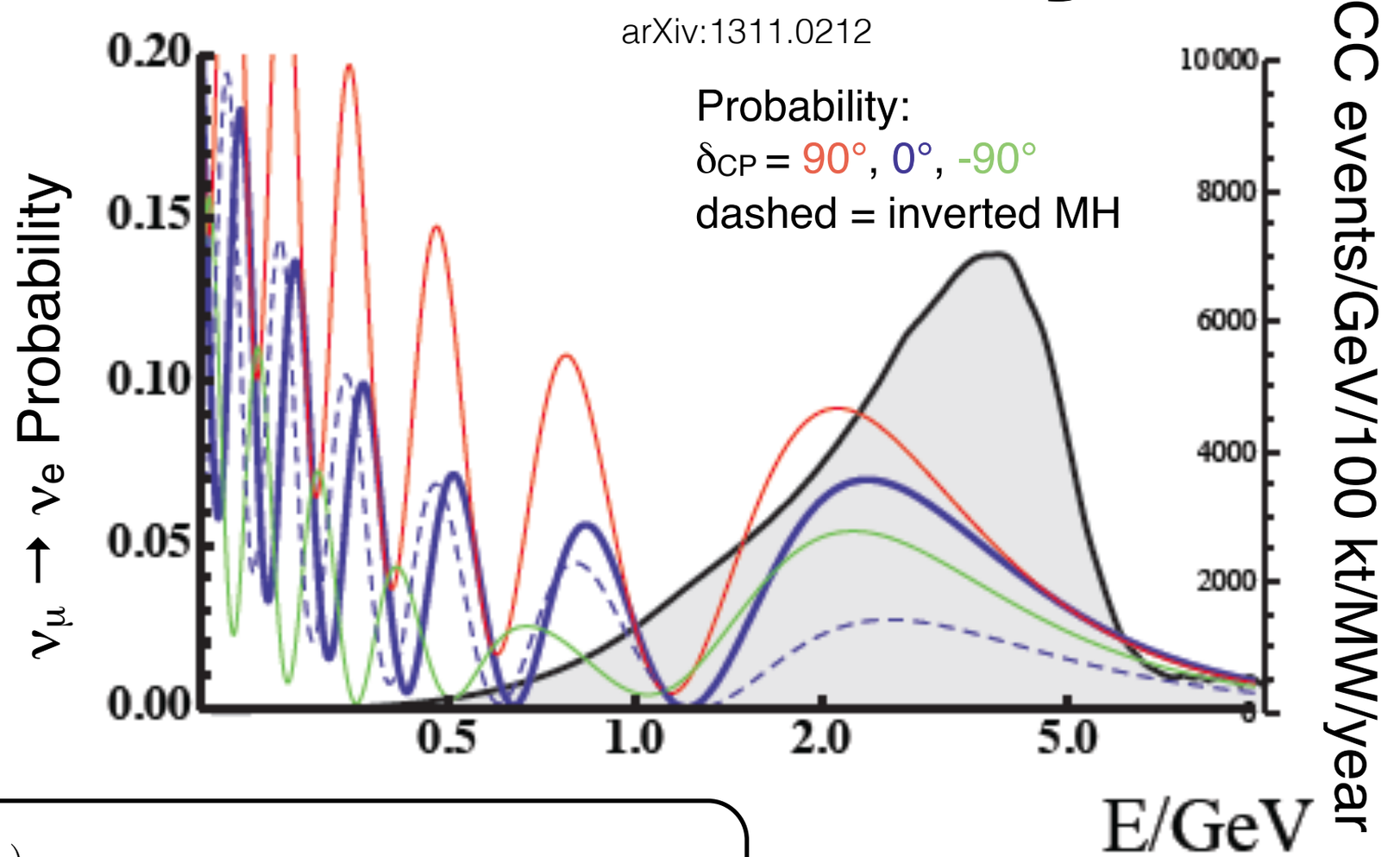
$$n + {}^{40}\mathrm{Ar} \rightarrow n + {}^{40}\mathrm{Ar}^*$$

Inelastic neutron scattering in argon was measured in the GEANIE flight path at WNR (*Phys. Rev. C* **85** (2012) 064614), but only for gammas up to 4 MeV.

There is evidence for ^{40}Ar gammas above 4 MeV as well (*Phys. Rev. C* **73** (2006) 054306)

LBNE Oscillation Analysis

- For the main oscillation analysis, we measure the energy and strength of the $\nu_\mu \rightarrow \nu_e$ oscillation probability.
- You have to see more than one node to break the degeneracy between mass hierarchy and δ_{CP}.



$$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2\theta_{23}\frac{\sin^2 2\theta_{13}}{(\hat{A}-1)^2}\sin^2((\hat{A}-1)\Delta)$$
$$+\alpha\frac{\sin\delta_{CP}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}}{\hat{A}(1-\hat{A})}\sin(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta)$$
$$+\alpha\frac{\cos\delta_{CP}\cos\theta_{13}\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}}{\hat{A}(1-\hat{A})}\cos(\Delta)\sin(\hat{A}\Delta)\sin((1-\hat{A})\Delta)$$
$$+\alpha^2\frac{\cos^2\theta_{23}\sin^2 2\theta_{12}}{\hat{A}^2}\sin^2(\hat{A}\Delta)$$

$$\alpha = \frac{\Delta m^2_{12}}{\Delta m^2_{13}} \quad \Delta = \frac{\Delta m^2_{13} L}{4E_\nu} \quad \hat{A} = \frac{2\sqrt{2}G_F n_e E_\nu}{\Delta m^2_{13}}$$

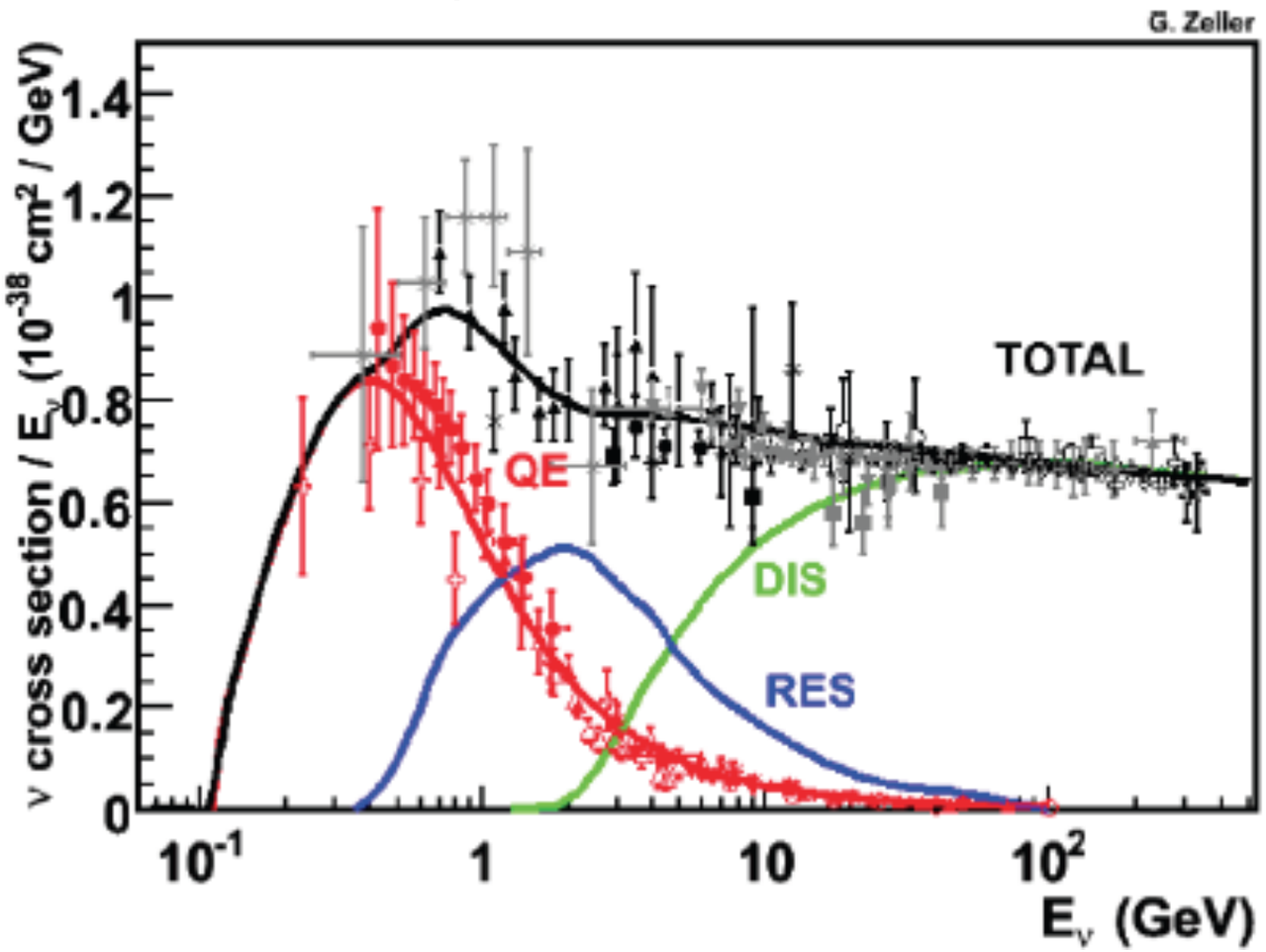
OK... So what?

Resonance Production Blues…

- The LBNE baseline locks you into a neutrino energy range that is harder to reconstruct than others…

- Resonance production and final state nuclear effects can hide energy from your reconstruction techniques.

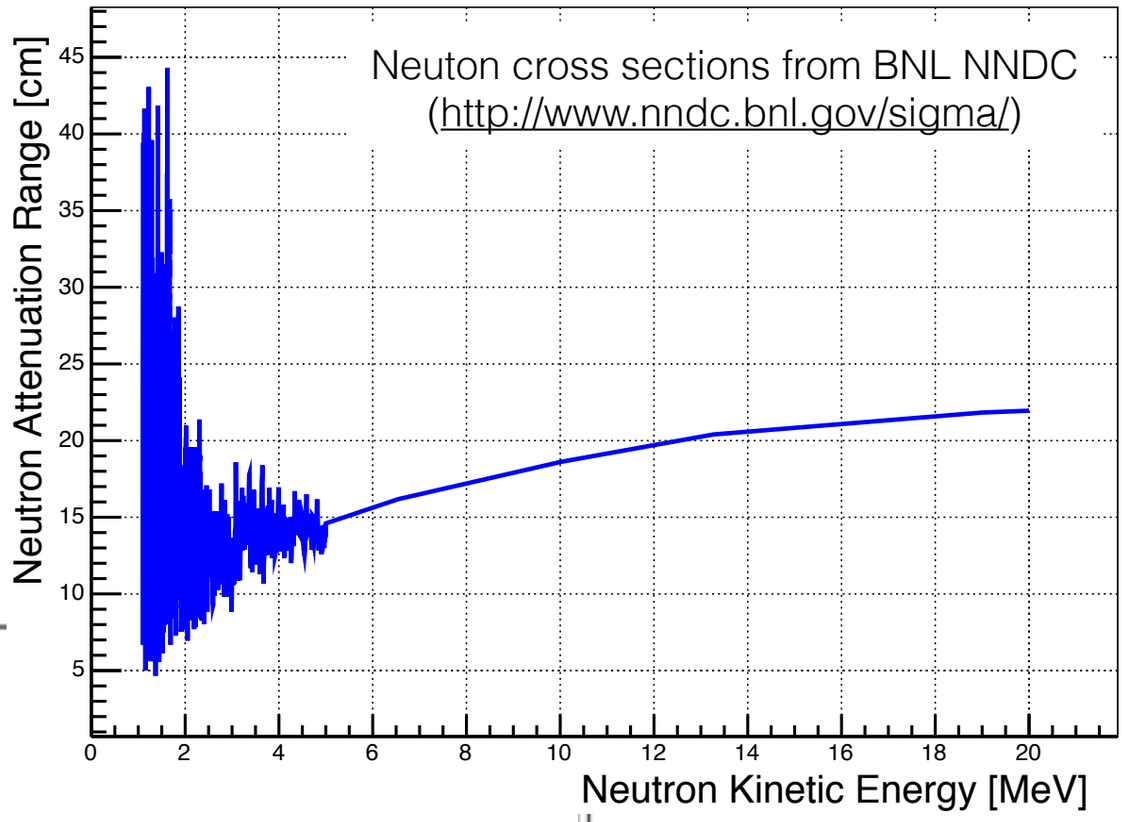
- Uncharged resonances can deposit energy far from the neutrino vertex, making those depositions hard to associate with said vertex and pushing events to lower energy

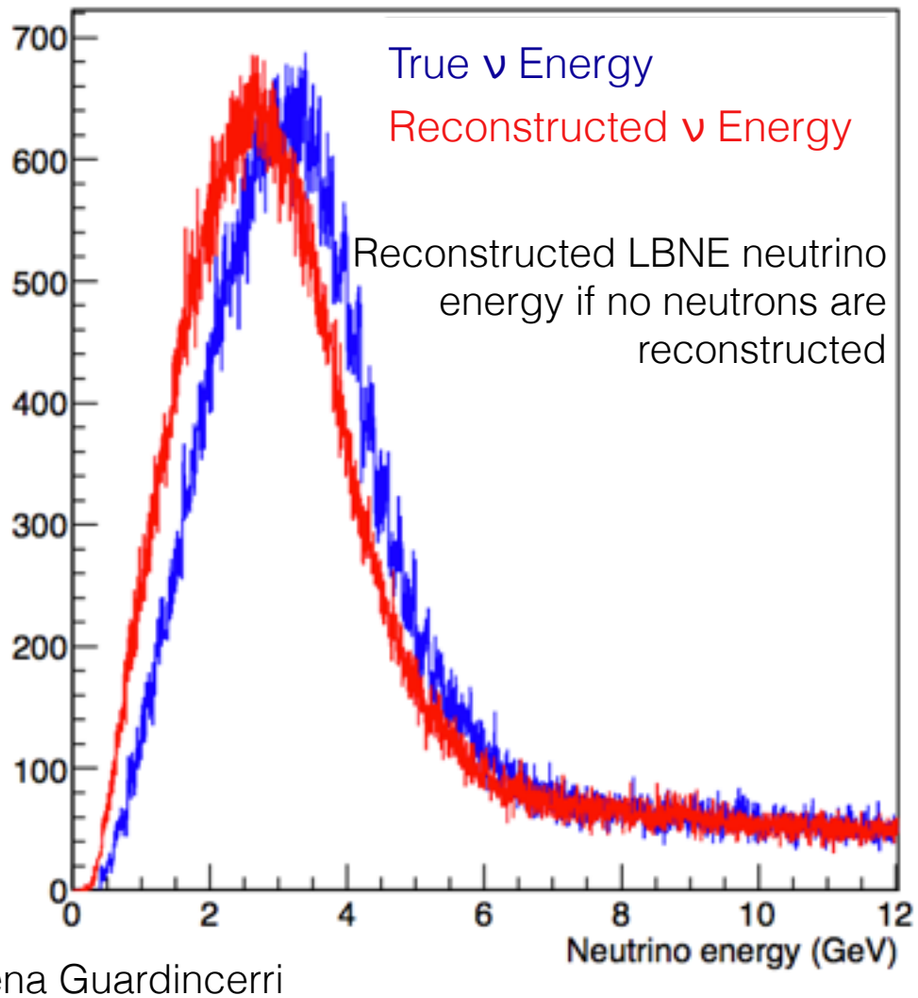


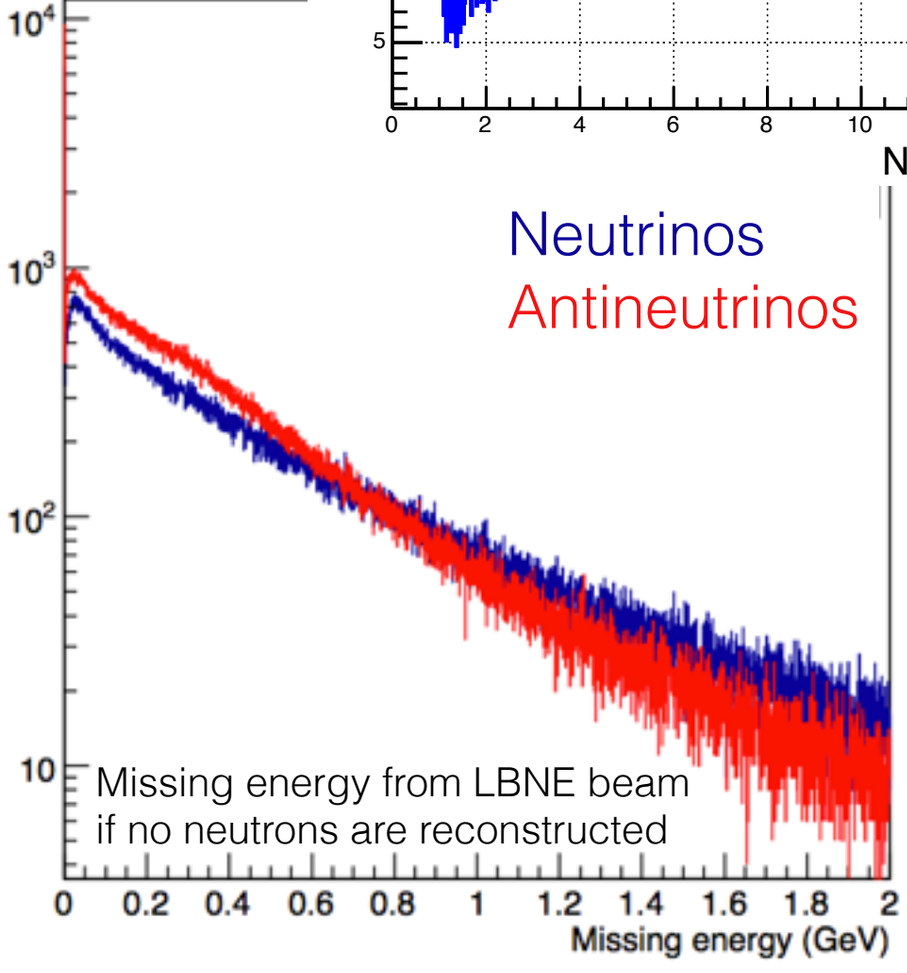
- We have to correct for this in the oscillation analysis!

Looking for Neutrons in LAr

- Reconstructing neutrons in LAr is still a really ill-defined problem.
- We don't even really know how far away from the primary vertex we should be looking!
- The library of neutron interactions will help.

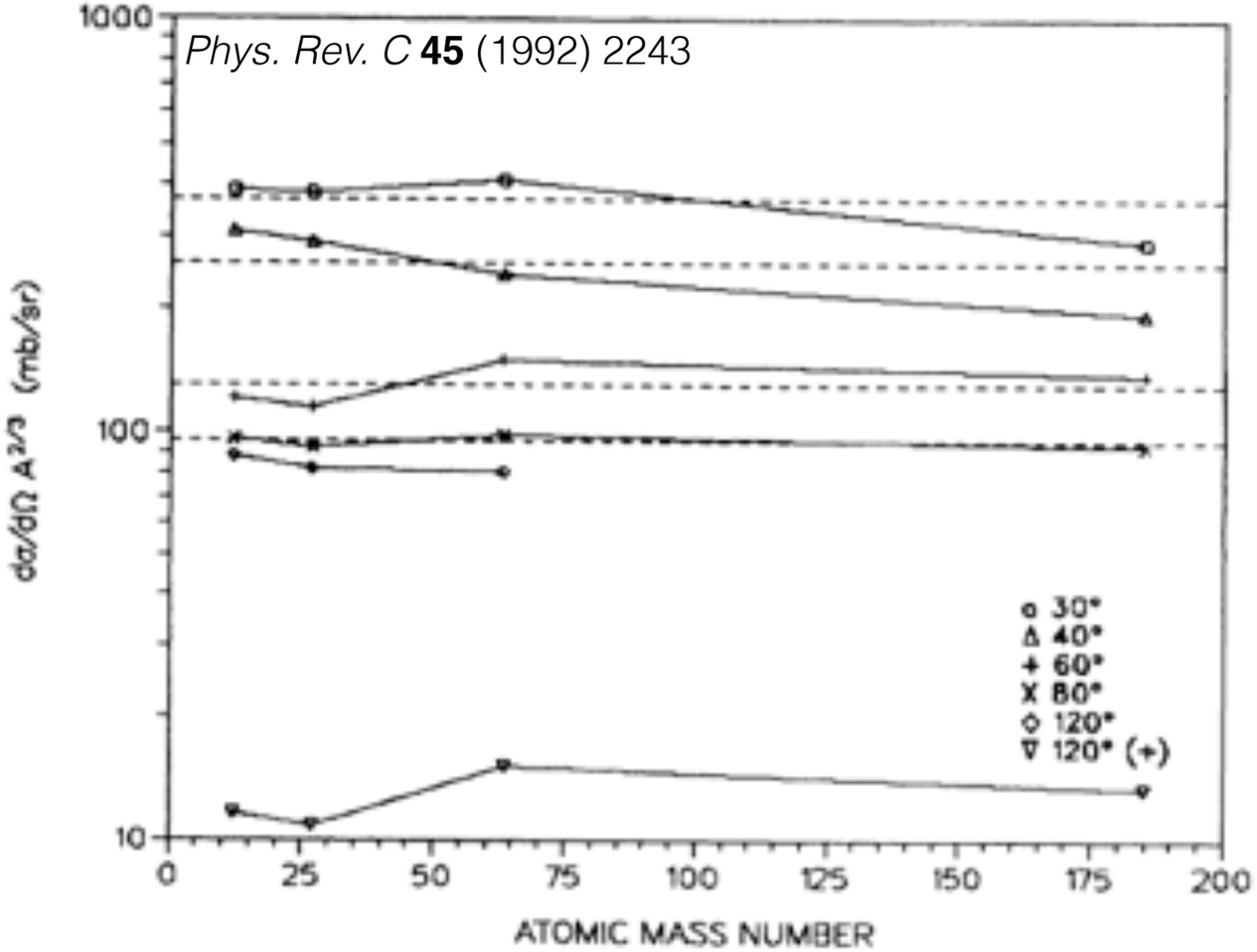


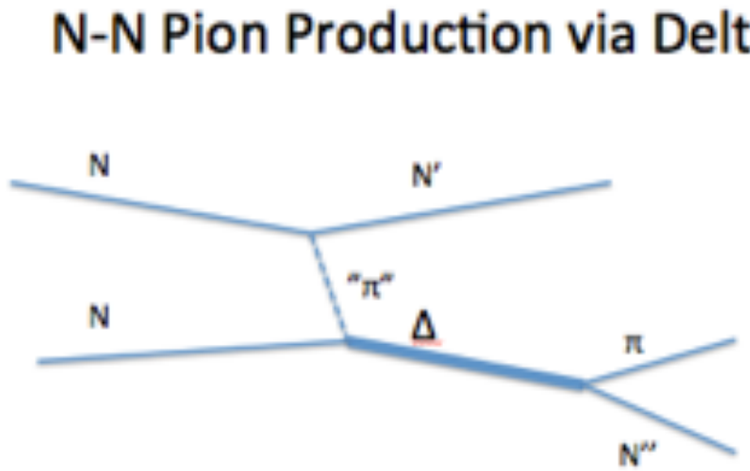




Pion Production in CAPTAIN

- Pion production has been measured in many nuclear targets
- $A^{2/3}$ scaling means that the production of pions is well predicted
- The ways that pions are absorbed in argon is not as well understood.
- The CAPTAIN high-energy, low-intensity run will address this!





$n-n$	π^-	$\frac{10}{12}$
	π^0	$\frac{2}{12}$
	π^+	0
$n-p$	π^-	$\frac{1}{12}$
	π^0	$\frac{4}{12}$
	π^+	$\frac{1}{12}$

Ratios will be modified by FSI

π^-	$\frac{11}{12}$
π^0	$\frac{6}{12}$
π^+	$\frac{1}{12}$

Conclusions

- The CAPTAIN (and related) neutron program will pin down a number of important systematic uncertainties vital to LBNE.

- The low-energy program will not work unless someone works to understand these nuclear physics backgrounds, but…

- …these measurements are *not* just important to the LBNE low-energy program!

- The main LBNE analysis needs this work as well, because resonance production is so strong at LBNE neutrino energies!

Thank you for your attention.
Any questions?

San Antonio Hot Springs in the Jemez Mountains near Los Alamos
Photograph by V.M. Gehman, December, 2005